Spectral Element Wakefield Simulations for High Energy Physics and Basic Energy Science Accelerators

Misun Min* and Paul Fischer, Argonne National Laboratory

Summary

Realistic simulations of accelerator Wakefield effects are critical for the successful design and construction of the International Linear Collider. As the electron bunch length of interest in modern accelerators gets shorter, the required computational resources become prohibitive for existing low-order techniques because of high memory requirements. We are developing high-order numerical tools with minimal numerical dispersions in order to help overcome the bottleneck faced by the accelerator community.

The International Linear Collider (ILC) is a top priority for the Department of Energy Office of High Energy Physics. The collider enables physicists to make the world's most precise measurements of nature's most fundamental particles. In order to achieve this scientific goal, the beam must be accelerated to reach GeV of the colliding beam through superconducting radio frequency.

The objective is to accelerate and transport the beam without degrading the beam emittance. The performance of accelerators is often limited by the Wavefield effect, which depends on the intensity and distribution of the electron bunch: the shorter the bunch, the stronger the effect. The ILC requires a very short bunch of a picosecond or less in order to achieve high luminosity. Future light sources may produce short x-ray pulses in the range of 100 femtoseconds. The demand for such short bunches poses computational challenges to scientists trying to improve beam quality.

A typical vacuum chamber dimension is 10 cm × 10 cm × 1 m, and the total number of grids is approximately 10^{12}. The corresponding computer memory required to simulate the chamber with traditional finite-difference time-domain methods is about 80 TB. To overcome this memory bottleneck, we are exploring high-order discretization. Specifically, we have developed a spectral element discontinuous Galerkin code for solving Maxwell's equations. The spectral convergence of the method makes the Wakefield problem completely tractable. Only 6×10^9 grids are needed to resolve a 500 GHz wavelength, with a reasonable memory requirement of only 400 GB.

Our code is built on top of an existing infrastructure within Nek5000, a spectral

* Mathematics and Computer Science Division, (630) 252-5380, mmin@mcs.anl.gov

element code originally designed at Argonne for fluid simulations. The new code may help deliver significant breakthrough discoveries in accelerator modeling.

Figure 1 shows the wire-frame rendering of the Advanced Photon Source small gap undulator chamber mesh and its cross-section. Figure 2 demonstrates our preliminary studies on a rectangular waveguide.

Our future simulations will involve spectral convergence and performance tests for cylindrical waveguides. We also will carry out the Wakefield calculations for the APS chamber mesh we have built.

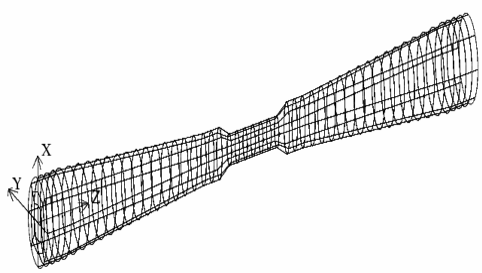

Figure 1. The Advanced Photon Source (APS) chamber mesh (top) and its cross-section (bottom).

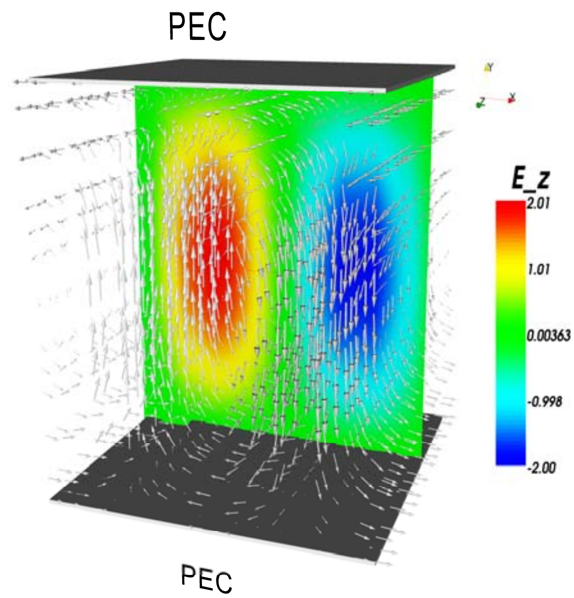

Figure 2. Rectangular waveguides with perfect electric conducting boundary in y-direction, and periodic boundaries in x- and z-directions. The color map represents the magnitude of E-field component in z-direction, and the arrows indicate the flow of H-field. The wave is propagating in the z-direction.

For further information on this subject contact:

Misun Min
Argonne National Laboratory
Mathematics and Computer Science Division
mmin@mcs.anl.gov
(630) 252- 5380

[*] Mathematics and Computer Science Division, (630) 252-5380, mmin@mcs.anl.gov